Original Article
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Comparative Analysis of Bone Mineral Density of the Lumbar Spine, Hip, and Proximal Humerus in Patients with Unilateral Rotator Cuff Tears

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Background: The proximal humerus, a common site for osteoporotic fractures, is frequently overlooked in osteoporosis evaluations. This study aimed to evaluate the relationship between the conventional bone mineral density (BMD) measurement (at the lumbar spine and femur) and the BMD measurement at both proximal humeri (the asymptomatic side and the side with a rotator cuff tear [RCT]) in patients with unilateral RCT. Furthermore, we investigated clinical features indicative of osteoporosis in RCT patients and assessed the utility of proximal humerus BMD measurements.

Methods: From April 2020 to September 2020, 87 patients who underwent arthroscopic repairs for unilateral RCTs were examined for age, onset, body mass index, menopause duration, passive range of motion, global fatty degeneration index, and RCT and retraction size. The regions of interest (ROIs) for the conventional BMD included the lumbar spine, femur neck, femur trochanter, and total femur. For the proximal humerus BMD, the ROIs included the head, lesser tuberosity, greater tuberosity (medial, middle, and lateral rows), and total humerus.

Results: The conventional BMD of the lumbar spine, femur neck, femur trochanter, and femur total were 1.090, 0.856, 0.781, and 0.945 g/cm^2, respectively. The head, lesser tuberosity, greater tuberosity (medial, middle, and lateral rows), and total BMD of the asymptomatic-side proximal humerus were 0.547, 0.544, 0.697, 0.642, 0.554, and 0.610 g/cm^2, respectively. The average of proximal humerus BMD was significantly lower than that of conventional BMD ($p < 0.001$). All ROIs BMD of the RCT-side proximal humerus were 0.497, 0.507, 0.619, 0.598, 0.517, and 0.560 g/cm^2. There was no correlation between the conventional BMD and each proximal humerus BMD. All ROI BMD of the RCT-side proximal humerus was not significant in the multiple regression analysis with age, onset, body mass index, passive range of motion, global fatty degeneration index, and RCT and retraction size ($p > 0.05$).

Conclusions: The proximal humerus BMD showed a completely different trend from that of conventional BMD and had no significant association with clinical features. Therefore, the proximal humerus BMD needs to be measured separately from the conventional BMD, as it may provide important information before rotator cuff repair surgery.

Keywords: *Bone mineral density, Spine, Femur, Proximal humerus, Rotator cuff tear*

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Osteoporosis is a systemic skeletal disorder characterized by the microarchitectural deterioration of bone tissues. As the elderly population increases, the prevalence of osteoporosis gradually increases as well.[1] In particular, decreased bone mass and osteoporotic bone changes in older people have been shown to increase the risk of fractures of the vertebral body, distal radius, proximal femur, and even proximal humerus.[2-4] Therefore, osteoporosis diagnosis and treatment are a big concern in the medical field since it increases morbidity and death, increasing the patient's economic burden. The shoulder is a non-weight-bearing joint and has an analogous macro- and micro-anatomic structure to the hip.[5] Similar to the wrist, osteoporotic fractures of the proximal humerus occur earlier than those of the hip and spine and have been reported to occur approximately 10 years before the occurrence of hip and spine fractures.[6-8] However, it has been overlooked in osteoporosis evaluation.[4,9,10] Risk factors for osteoporosis in the shoulder include a rotator cuff tear (RCT), frozen shoulder, and musculoskeletal injury, causing shoulder immobility like shoulder dislocation. Patients with RCTs are more likely to develop local osteoporosis due to a lack of mechanical stimulation, regardless of their overall osteoporosis risk.[11]

Frozen shoulder has been reported to be induced by hormones and relatively low bone mineral density (BMD) in women, and osteoporosis can occur in the shoulder due to subsequent immobilization by injury.[12] Recently, the number of patients with shoulder pain has been increasing, and RCT is a common cause of shoulder pain and limited shoulder function in adult patients.[13] As the shoulder movement decreases, loss of physical stimulation at the tendon insertion point eventually leads to osteopenic changes as described by Wolff's low. Some clinical studies have also shown osteopenic changes in the greater tuberosity (GT) in patients with chronic RCTs.[14,15]

In rotator cuff repair surgery, suture anchors are inserted in the GT of the proximal humerus, namely the medial, middle, and lateral rows of the GT. However, the suture anchor may be loosened by the osteoporotic change in the proximal humerus, leading to failure of surgical treatment.[16] In the proximal humerus, typical RCTs and fractures most commonly requiring surgical treatment are all associated with bone quality. Bone quality of the proximal humerus is important not only for the internal fixation of the fracture but also for the successful surgical treatment of RCT. If osteoporosis is diagnosed in the proximal humerus before RC repair, complications such as anchor pull-out can be avoided by planning to use a full-threaded suture anchor or insert an anchor without under-tapping or tapping.[17] Despite the significant clinical relevance of the bone quality of the proximal humerus, BMD measurements in this region have been evaluated in only a small number of studies.[18] BMD examination of the proximal humerus was often neglected, and most orthopedic surgeons predicted bone quality using conventional BMD, which was measured at the lumbar spine and femur. There are a number of important questions related to this issue. Firstly, is the conventional BMD related to the proximal humerus BMD? Secondly, is there a BMD difference between suture anchor insertion sites (medial, middle, and lateral rows of the GT)? Lastly, if the BMD decreases in RCT patients, is it related to osteoporosis according to clinical features?

With these questions, we intended to measure the conventional BMD (lumbar spine and femur) and bilateral proximal humerus BMD in unilateral RCT patients. The purpose of this study was to find the correlation between each BMD and conduct an analysis according to clinical features.

METHODS

This study obtained approval from the Institutional Review Board of Chungnam National University Hospital (IRB No. CNUH 2020-12-040). Informed consent was waived as this study was performed retrospectively. Consent to publish the photo showing the arm position was obtained from the author.

Patients

We performed a retrospective study using prospectively collected data that included patients with unilateral RCTs from April 2020 to September 2020. We studied 101 patients with RCTs, and the inclusion criteria were as follows: (1) unilateral RCTs, (2) symptoms persisting for more than 6 months without using osteoporosis medication, and (3) measurement of both conventional BMD (lumbar spine and femur) and proximal humerus BMD. The exclusion criteria were as follows: (1) patients with diabetes, (2) smokers, (3) bilateral shoulder pain, and (4) previous surgery of the shoulder, hip, and spine. Consequently, 87 patients were included in this study (Fig. 1).

BMD Measurement

In measuring BMD, linear scanning and area scanning techniques are commonly used. The linear scanning technique is mainly used in the distal radius, and the area scanning technique includes dual-photon absorptiometry, quantitative ultrasound, quantitative computed tomography (qCT), and dual-energy x-ray absorptiometry (DEXA). Although qCT can assess volumetric BMD and actual trabecular bone density, it is difficult to access in an actual clinical setting. DEXA is a more common and widely accessible tool for determining the reliability of cancellous bones such as the spine and femur.

Although the shoulder joint is a non-weight-bearing joint, it has a macro- and micro-anatomical analogous structure to the hip. There are several cancellous bones, and the cortical shell is thin in the proximal humerus. So, in this study, BMD was measured using a DEXA scanner. We measured the BMD of the lumbar spine and femur as the conventional BMD and the bilateral proximal humeri BMD using a DEXA scanner (ARIA, General Electric Company). For the lumbar spine, the average BMD value from L1 to L4, excluding values with T-score outside of 1 standard deviation, was used, and the neck, trochanter, and total BMD values for the femur were used. The region of interest (ROI) of the proximal humerus was measured by determining the head, lesser tuberosity (LT), medial row of the GT, middle row of the GT, lateral row of the GT, and total regions of the proximal humerus (Fig. 2). Oh et al.[19] reported the BMD measurement of the proximal humerus with the shoulder externally rotated by 30° to avoid overlapping of the bicipital groove. Similarly, we measured the BMD of the proximal humerus with an ex-

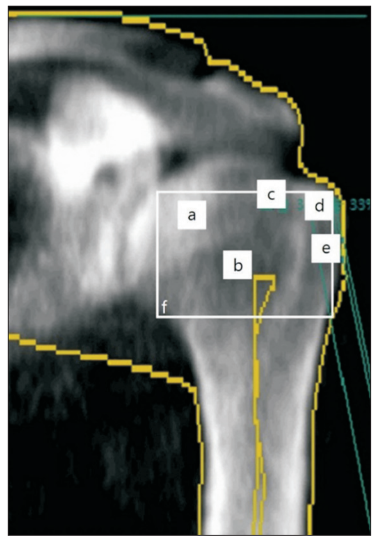

Fig. 2. Regions of interest for bone mineral density measurement in the proximal humerus. (a) Head, (b) lesser tuberosity, (c) medial row of the greater tuberosity (GT), (d) middle row of the GT, (e) lateral row of the GT, and (f) total region.

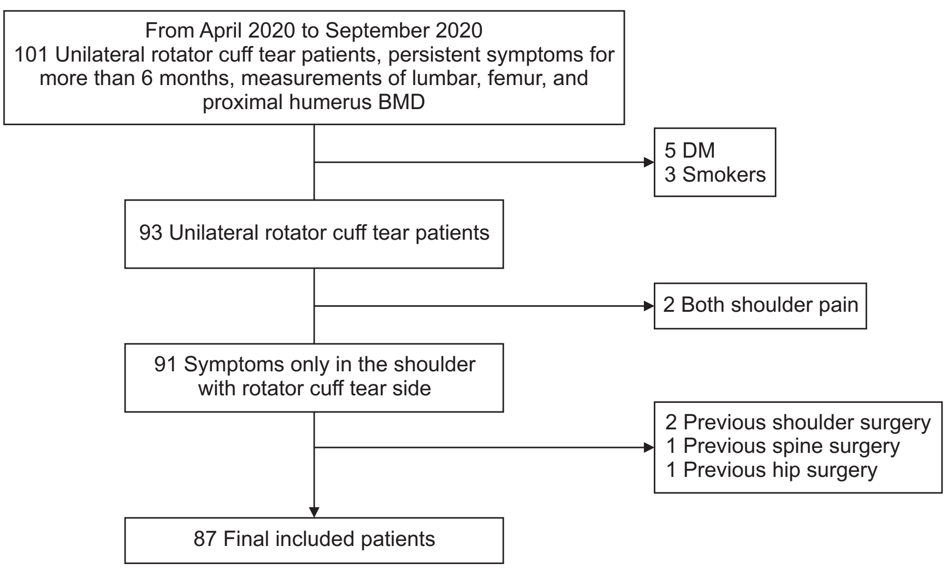

Fig. 1. Flowchart of patient selection. BMD: bone mineral density, DM: diabetes mellitus.

Fig. 3. Position of the arm for measurement of proximal humerus bone mineral density.

ternal rotation of 30° for the shoulder, 10° for the arm, and 90° for the elbow flexion (Fig. 3). In the head, LT, and GT, we drew 0.8 × 0.8 cm^2-sized squares for the ROI. The total region of the proximal humerus was defined as the square drawn from the inferomedial point of the anatomical neck to the lateral margin of the GT.

Clinical Assessment

Clinical data including age, onset, body mass index (BMI), arm dominance, and menopause duration were collected. In addition, passive range of motion (forward flexion, abduction, external rotation, and internal rotation) was measured before surgery, and RCT and retraction size were measured using a probe during arthroscopic surgery. In the RCT-side MRI, to find out the correlation with sarcopenia, the global fatty degeneration index (GFDI) according to the Goutallier classification of the supraspinatus, infraspinatus, and subscapularis muscles was also investigated. The Goutallier classification (G0–G4) was used in the oblique sagittal T1-weighted image. The sagittal image selected was the most lateral image in which the scapular spine was still in contact with the scapular body.

Statistical Analysis

All statistical analyses were carried out using SPSS software version 25.0 (IBM Corp.), and $p < 0.05$ was considered statistically significant. The Shapiro-Wilk test was used to detect normality distribution. Average comparison was performed using the paired *t*-test and independent *t*-test for the parametric variables and the Mann-Whitney *U*-test for the non-parametric variables. Pearson's correlation coefficient was used to compare the conventional BMD and the asymptomatic side and the RCT side of proximal humerus BMD, and correlations according to age and menopausal duration were investigated. In addition, the RCT-side BMD of the proximal humerus was analyzed for age, onset, BMI, passive range of motion, GFDI, and RCT and retraction size factors through multiple regression analysis.

Table 1. Basic Characteristics of the Enrolled Patients

Variable	Value (n = 87)
Age (yr)	64.1 ± 5.7 (52–79)
50–59	16 (18.4)
60–69	54 (62.1)
70–79	17 (19.5)
Sex (male : female)	30 (34.5) : 57 (65.5)
Menopause age (yr, n = 57)	52.1 ± 2.9 (46–59)
Menopause duration (yr, n = 57)	10.9 ± 6.0 (1–26)
Dominant arm (right : left)	79 (90.8) : 8 (9.2)
RCT shoulder (right : left)	59 (67.8) : 28 (32.2)
Onset (mo)	17.4 ± 15.7 (6–60)
Height (cm)	158.3 ± 8.5 (138–178)
Weight (kg)	62.7 ± 8.9 (42–82)
BMI (kg/m^2)	25.0 ± 2.7 (18.2–32.6)
GFDI	1.4 ± 0.7 (0.3–3)
RCT size (cm)	2.2 ± 0.6 (0.5–5)
Retraction size (cm)	1.6 ± 0.8 (0.5–4)

Values are presented as mean ± standard deviation (range) or number (%).
RCT: rotator cuff tear, BMI: body mass index, GFDI: global fatty degeneration index.

RESULTS

The average age of the 87 enrolled patients (30 men and 57 women) was 64.1 ± 5.7 years. The mean duration of symptoms was 17.4 ± 15.7 months (range, 6–60 months), the average BMI was 25.0 ± 2.7 kg/m^2 (range, 18.2–32.6 kg/m^2), the GFDI was 1.4 ± 0.7 (range, 0.3–3), and the average RCT and retraction size observed on arthroscopy was 2.2 ± 0.6 cm (range, 0.5–5 cm) and 1.6 ± 0.8 cm (range, 0.5–4 cm), respectively (Table 1). When compared by sex, the average age of men was 3.3 years older, and there was no significant difference (Table 2). The mean age of menopause

Table 2. Comparsion of the Characteristics of the Enrolled Patients by Sex

Variable	Male (n = 30)	Female (n = 57)	p-value
Age (yr)	66.3 ± 5.2 (60–76)	63.0 ± 5.6 (52–79)	0.011
Onset of symptom (mo)	15.9	17.8	0.205
BMI (kg/m^2)	25.0	25.0	0.970
Menopause age (yr)	-	52.1 (46–59)	
Duration of menopause (yr)	-	10.9 (1–26)	
GFDI	1.3	1.5	0.287
RCT size (cm)	2.4	2.2	0.200
Retraction size (cm)	1.6	1.6	0.788

Values are presented as mean ± standard deviation (range) unless otherwise indicated.
BMI: body mass index, GFDI: global fatty degeneration index, RCT: rotator cuff tear.

Table 3. BMD and T-score of the Lumbar and Femur in All Patients

ROI	Value
Lumbar BMD (g/cm^2)	1.090 ± 0.177 (0.779 to 1.548)
Femur neck BMD (g/cm^2)	0.856 ± 0.140 (0.553 to 1.240)
Femur trochanteric BMD (g/cm^2)	0.781 ± 0.137 (0.484 to 1.198)
Femur total BMD (g/cm^2)	0.945 ± 0.136 (0.636 to 1.395)
Lumbar T-score	–0.514 ± 1.434 (–3.0 to 3.0)
Femur neck T-score	–0.734 ± 1.139 (–3.2 to 2.5)
Femur trochanteric T-score	0.263 ± 1.174 (–2.3 to 4.2)
Femur total T-score	–0.162 ± 1.159 (–2.8 to 3.5)

Values are presented as mean ± standard deviation (range).
BMD: bone mineral density, ROI: region of interest.

in women was 52.1 years and duration was 10.9 years. In the data of this study, 10 cases were diagnosed with osteoporosis based on the T-scores of the lumbar and femur.

Conventional BMDs of the lumbar spine, femur neck, femur trochanter, and femur total were 1.090 ± 0.177 g/cm^2 (range, 0.779–1.548), 0.856 ± 0.140 g/cm^2 (range, 0.553–1.240), 0.781 ± 0.137 g/cm^2 (range, 0.484–1.198), and 0.945 ± 0.136 g/cm^2 (range, 0.636–1.395), respectively (Table 3). The asymptomatic-side and RCT-side BMD in the proximal humerus are shown in Table 4. When comparing averages of all conventional BMD and proximal humerus BMD, all conventional BMD was higher than all proximal humerus BMD (all $p < 0.001$). In particular, the BMD results in the asymptomatic proximal humerus were significantly lower in the order of GT medial row, GT middle row, and GT lateral row (all $p < 0.001$). The BMD results in the RCT-side proximal humerus were also lower in the order of GT medial row, GT middle row, and GT lateral row, but there was no significant difference between the GT medial row and GT middle row ($p = 0.173$), and the others were significantly different (all $p < 0.001$). In all ROIs of the proximal humerus, the RCT-side BMD showed significantly lower results than the asymptomatic-side BMD (all $p < 0.05$). In addition, all ROI BMD of the bilateral proximal humeri showed significantly lower results than all the conventional BMD (all $p < 0.001$) (Table 4, Fig. 4).

In the correlation coefficient analysis of the conventional BMD and the proximal humerus BMD, neither the asymptomatic side nor the RCT side showed any correlation with the conventional BMD (Tables 5 and 6). While some results showed negative correlations, there was no overall correlation between the conventional BMD and proximal humerus BMD.

When each BMD was compared separately, conventional BMD did not show a difference according to sex in the data of this study. The conventional BMD of men was 1.089, 0.882, 0.807, and 0.954 g/cm^2 and that of women was 1.090, 0.842, 0.767, and 0.940 g/cm^2. There was no significant difference between the 2 groups ($p = 0.979$, $p = 0.204$, $p = 0.152$, and $p = 0.610$, respectively). However, the bilateral proximal humeri BMD in men showed significantly higher results than in women in all of the ROIs (all $p < 0.05$, except for the GT lateral row of the RCT side, $p = 0.139$) (Table 7). In the conventional BMD with increasing age, the correlation coefficients were –0.624, –0.520, –0.411, and –0.450 for the lumbar spine, femur neck, trochanter, and total, respectively (all $p < 0.001$). However, the asymptomatic-side and RCT-side BMD of the proximal humerus did not show a significant relationship with age ($p > 0.05$) (Table 8). The correlation coefficients of the conventional BMD according to menopause duration in women were –0.456, –0.467, –0.327, and –0.348 for the lumbar spine, femur neck, trochanter, and total, respectively ($p = 0.000$, $p = 0.000$, $p = 0.013$, and $p = 0.008$, respectively). However, the asymptomatic-side and RCT-side BMD of the proximal humerus did not show a significant correlation as menopause duration increased ($p > 0.05$), except for the LT region on the RCT side ($p = 0.023$) (Table 9).

For the RCT-side proximal humerus BMD, the determination coefficients of the head, LT, GT medial row, middle low, lateral row, and total were 0.198, 0.152, 0.124,

Table 4. BMD of Asymptomatic-Side and Rotator Cuff Tear-Side Proximal Humerus

ROI	Asymptomatic-side BMD (g/cm^2)	RCT-side BMD (g/cm^2)	*p*-value*
Head	0.547 ± 0.150 (0.229–0.936)	0.497 ± 0.158 (0.044–0.832)	< 0.001
LT	0.544 ± 0.137 (0.282–0.921)	0.507 ± 0.125 (0.150–0.780)	0.001
GT medial row	0.697 ± 0.137 (0.429–1.070)	0.619 ± 0.159 (0.200–1.212)	< 0.001
GT middle row	0.642 ± 0.120 (0.393–0.982)	0.598 ± 0.153 (0.097–0.951)	0.002
GT lateral row	0.554 ± 0.103 (0.375–0.964)	0.517 ± 0.114 (0.055–0.747)	0.002
Total	0.610 ± 0.101 (0.407–0.882)	0.560 ± 0.118 (0.114–0.860)	< 0.001

Values are presented as mean ± standard deviation (range).
BMD: bone mineral density, ROI: region of interest, RCT: rotator cuff tear, LT: lesser tuberosity, GT: greater tuberosity.
*Paired *t*-test; $p < 0.05$ denotes statistical significance.

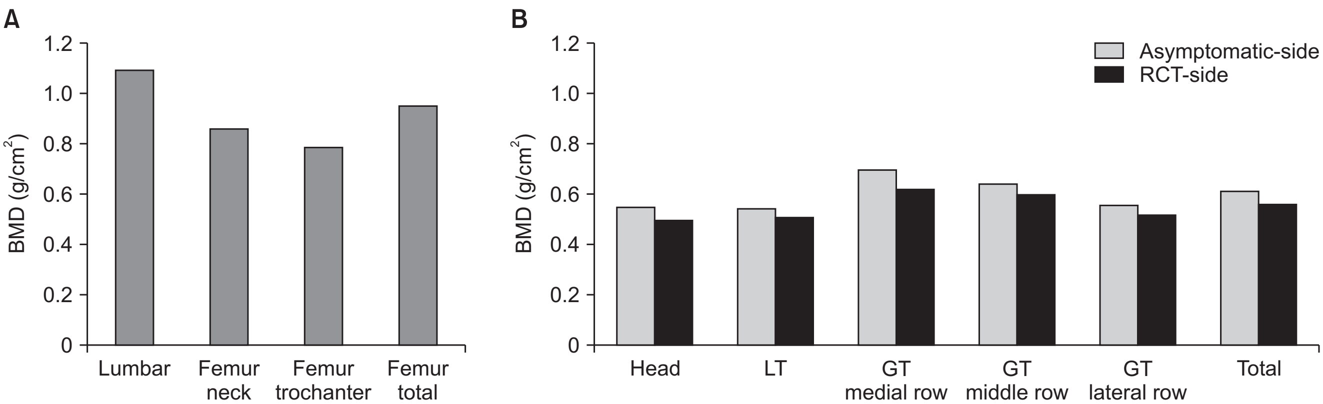

Fig. 4. Comparative plot of the lumbar and femur (A) and proximal humerus (B) bone mineral density (BMD). All lumbar and femur BMD was higher than all proximal humerus BMD (all $p < 0.001$). In addition, all asymptomatic-side BMD was higher than all rotator cuff tear (RCT)-side BMD in the proximal humerus (all $p < 0.01$). LT: lesser tuberosity, GT: greater tuberosity.

Table 5. Pearson's Correlation Coefficients (R) for the Asymptomatic-Side Proximal Humerus BMD and Conventional BMD

ROI		Head	LT	Med row	Mid row	Lat row	Total
Lumbar spine	R	–0.122	0.064	–0.028	–0.111	–0.181	–0.111
	p-value*	0.262	0.555	0.800	0.304	0.094	0.307
Femur neck	R	–0.025	0.139	0.046	0.011	–0.064	–0.007
	p-value*	0.820	0.199	0.671	0.922	0.553	0.952
Femur trochanter	R	–0.034	0.179	0.053	–0.010	–0.073	0.020
	p-value*	0.752	0.097	0.625	0.926	0.500	0.851
Femur total	R	–0.058	0.125	0.016	–0.051	–0.104	–0.027
	p-value*	0.596	0.247	0.884	0.640	0.337	0.800

BMD: bone mineral density, ROI: region of interest, LT: lesser tuberosity, Med row: medial row of the greater tuberosity, Mid row: middle row of the greater tuberosity, Lat row: lateral row of the greater tuberosity.
*Pearson's correlation coefficient significance; $p < 0.05$ denotes statistical significance.

Table 6. Pearson's Correlation Coefficients (R) for the Rotator Cuff Tear-side Proximal Humerus BMD and Conventional BMD

ROI		Head	LT	Med row	Mid row	Lat row	Total
Lumbar spine	R	–0.066	0.091	–0.060	0.007	0.012	–0.025
	p-value*	0.542	0.401	0.579	0.947	0.912	0.819
Femur neck	R	0.035	0.143	0.057	0.107	0.015	0.058
	p-value*	0.745	0.187	0.599	0.323	0.889	0.591
Femur trochanter	R	0.056	0.180	0.065	0.102	0.033	0.096
	p-value*	0.609	0.095	0.547	0.348	0.762	0.379
Femur total	R	0.016	0.125	–0.015	0.039	–0.019	0.023
	p-value*	0.881	0.249	0.889	0.718	0.860	0.829

BMD: bone mineral density, ROI: region of interest, LT: lesser tuberosity, Med row: medial row of the greater tuberosity, Mid row: middle row of the greater tuberosity, Lat row: lateral row of the greater tuberosity.
*Pearson's correlation coefficient significance; $p < 0.05$ denotes statistical significance.

Table 7. Differences in the Bilateral Proximal Humeri BMD between Men and Women

ROI	Asymptomatic-side BMD (g/cm^2)			RCT-side BMD (g/cm^2)		
	Male (n = 30)	Female (n = 57)	*p*-value*	Male (n = 30)	Female (n = 57)	*p*-value*
Head	0.646	0.494	< 0.001	0.598	0.443	< 0.001
LT	0.586	0.523	0.041	0.565	0.477	0.002
GT medial row	0.773	0.657	< 0.001	0.715	0.569	< 0.001
GT middle row	0.698	0.612	0.001	0.681	0.554	< 0.001
GT lateral row	0.585	0.538	0.042	0.542	0.504	0.139
Total	0.668	0.580	< 0.001	0.629	0.523	< 0.001

BMD: bone mineral density, ROI: region of interest, RCT: rotator cuff tear, LT: lesser tuberosity, GT: greater tuberosity.
*Independent *t*-test; $p < 0.05$ denotes statistical significance.

0.175, 0.196, and 0.206, respectively, in multiple regression analysis according to age, onset, BMI, passive ROM, GFDI, and RCT and retraction size. The determination coefficient showed a low value, and the analysis of variance was not significant (all $p > 0.05$). In addition, no significance was found even though multiple regression analysis was performed for men and women separately (all $p > 0.05$).

DISCUSSION

There are studies on the necessity to evaluate the site-specific BMD of the proximal humerus because of its individual and regional variability, and there are wide variations in BMD at different skeletal sites.[12,18,20-23] Oh et al.[19] reported a Pearson's correlation coefficient of 0.506 to 0.679 with conventional BMD only for GT BMD among GT, head, and neck BMD of the proximal humerus. However, in our study, all ROIs of both the asymptomatic-side and RCT-side proximal humeri were not correlated with the conventional BMD. This was probably due to individual variability. When the conventional BMD and proximal humerus BMD were analyzed separately, no sex difference was noted in the conventional BMD, but all ROIs of both the asymptomatic-side and RCT-side proximal humeri were higher in men than in women. In addition, the conventional BMD showed a decreased correlation with age and menopause duration, whereas all ROIs of both the asymptomatic-side and RCT-side proximal humeri showed no correlations at all. All the proximal humerus BMDs showed lower results than those of the lumbar spine and hip.

Doetsch et al.[20] have reported that the proximal hu-

Table 8. Pearson's Correlation Coefficients (R) for Age and Bilateral Proximal Humeri

ROI		Age	
		Asymptomatic-side	RCT-side
Head	R	0.126	0.116
	p-value*	0.245	0.284
LT	R	–0.044	–0.113
	p-value*	0.687	0.298
GT medial row	R	0.092	0.101
	p-value*	0.394	0.354
GT middle row	R	0.161	–0.081
	p-value*	0.135	0.457
GT lateral row	R	0.164	–0.113
	p-value*	0.129	0.297
Total	R	0.144	0.004
	p-value*	0.184	0.971

ROI: region of interest, RCT: rotator cuff tear, LT: lesser tuberosity, GT: greater tuberosity.
*Pearson's correlation coefficient significance; $p < 0.05$ denotes statistical significance.

Table 9. Pearson's Correlation Coefficients (R) for Menopause Duration and Bilateral Proximal Humeri

ROI		Menopause duration	
		Asymptomatic-side	RCT-side
Head	R	–0.109	–0.139
	p-value*	0.418	0.302
LT	R	–0.106	–0.301
	p-value*	0.434	0.023
GT medial row	R	–0.006	–0.168
	p-value*	0.963	0.212
GT middle row	R	0.125	–0.250
	p-value*	0.354	0.061
GT lateral row	R	0.038	–0.229
	p-value*	0.777	0.086
Total	R	–0.007	–0.247
	p-value*	0.959	0.064

ROI: region of interest, RCT: rotator cuff tear, LT: lesser tuberosity, GT: greater tuberosity.
*Pearson's correlation coefficient significance; $p < 0.05$ denotes statistical significance.

merus BMD is lower than the hip BMD in healthy Danish adult women. Because the proximal humerus has a lower bone density than the hip and lumbar spine, it is more susceptible to osteoporotic fractures, making it important to measure the BMD of the proximal humerus to predict osteoporotic fractures. As a result, the conventional BMD and proximal humerus BMD show completely different trends and are different from other study results, so there may be limitations in inferring the proximal humerus BMD with conventional BMD. However, based on our study results, humerus BMD was lower than conventional BMD in both men and women. This was considered regional variability.

In this study, conventional BMD did not show any sex differences and showed a correlation between age and menopausal period, whereas proximal humerus BMD showed sex differences and had no relationship between age and menopausal period. This was thought to be a variation according to the skeletal site.

According to Meyer et al.,[24] as a result of measuring the humeral head BMD of 14 RCTs with high-resolution micro-computed tomography (CT) scans in a cadaver study, it was found that cancellous bone density in the GT was decreased by more than 50%. Waldorff et al.[15] reported a BMD decrease in patients with rotator cuff disease, suggesting that this induces osteopenia of the GT by osteoclasts. We also showed a significant decrease in all ROIs on the RCT side compared with the BMD of the asymptomatic-side proximal humerus. The proximal humerus BMD in patients with RCTs is related to the surgical treatment outcomes, so it needs to be confirmed, and it can be an important variable as a preoperative prognostic factor. For these reasons, the first question, whether conventional BMD was related to proximal humerus BMD, had no correlation and showed a different tendency, so there would be limitations in inferring proximal humerus BMD with conventional BMD.

One of the strengths of this study is that the BMD of each row of GT inserted with suture anchors was measured. Regarding our second question, the BMD of the proximal humerus was lower in the order of medial, middle, and lateral rows of the GT. In rotator cuff repair, the insertion of anchors uses the medial, middle, and lateral rows of the GT, and recently, a triple-row suture technique has been reported to obtain solid repair by inserting all anchors in each of the 3 rows.[25] BMD measurement for each row of the GT on the proximal humerus before RCT repair is useful in preoperative planning for the suture anchor insertion site during rotator cuff repair.

In the last question, the lowering of BMD in RCT patients was verified in this study as well as in other studies. Few studies have investigated the association between affected proximal humerus BMD and clinical features in patients with RCTs. In our study, the BMD of men, women, and all (men and women) in the RCT-side proximal humerus was not significantly different in the multiple regression analysis according to age, symptom duration, passive ROM, GFDI, and RCT and retraction size. Oh et al.[19] reported that the BMD of patients with RCT only decreased with age and in women, and it was not associated with symptom duration, stiffness, hand dominance, tear size, retraction, fatty degeneration of the cuff muscle, smoking, and degree of sports activity and working activity. Because the BMD of the RCT-side proximal humerus shows a different trend according to several studies, further research on predictive factors according to clinical features for standardization is required.

This study has several limitations. First, the number of included patients was small, most patients were in their 60s, and the number of patients in their 50s and 70s was relatively small; therefore, age-related errors may have occurred in the BMD results, so future cohort studies with a wider range of patient ages will be needed. Second, the 2-dimensional nature of DEXA images limits the ability to assess the specific distribution of the bone, which is highly relevant to rotator cuff disease and repair. For the measurement of proximal humerus BMD, a comparative study between DEXA and qCT capable of precise measurement is needed. Third, even if the posture for measuring BMD is the same, the average angle range of the bicipital groove varies from 5° to 97°, so it could affect the BMD value of the LT site along the bicipital groove, and this could not be considered. Further studies will be needed to improve the generalizability of the BMD measurements.

The BMD in the proximal humerus differed from conventional BMD measurements and showed no correlation with them, varying according to sex, age, and the duration of menopause. Patients with RCTs exhibited lower BMD in the proximal humerus compared to those with a normal cuff side. Consequently, assessing the BMD of the proximal humerus can significantly contribute to the preoperative planning of shoulder surgeries, including those for RCTs, potentially improving surgical outcomes. Given the observed differences across each row of the GT, this measure could serve as a useful method for determining the optimal locations for suture anchor insertion during preoperative planning. Furthermore, BMD assessments are crucial for patients with RCTs due to the lack of comprehensive data on the relationship between clinical features and BMD in the proximal humerus, rendering such associations uncertain and unpredictable.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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